Chief Engineer's Corner

Dr. Joe Meltzer and Col. Chuck Whited

One of Aerospace's core competencies is to provide formal verification of mission and launch readiness. Independent Readiness Reviews (IRR) supported by Aerospace provide a step in the process to achieve this formal certification. Many IRR issues have been raised and resolved through the dedicated involvement of Aerospace's technically capable personnel. Their continued support ensures the excellence found in our national security space systems. The following article reports on one potential failure uncovered by a recent review.

Potential Titan IV Mission Failure Averted by an Independent Readiness Review Team

Dr. S. R. Lin, Director
Structural Technology Department
Vehicle Systems Division

Background

The Titan IV Stage II nozzle extension, referred to as the skirt, is lined with an asbestos phenolic composite material that insulates the structural materials from high temperature combustion gases. The skirt is attached to the bottom of the engine nozzle to maximize performance. It changes the expansion ratio of the nozzle to meet the Air Force requirements of Titan missions.

Due to supply difficulties with the phenolic resin used in this composite insulator, the engine contractor, Aerojet, selected a replacement resin. The new resin had been successfully used in other applications, notably the Stage I silica phenolic skirt of the same Titan launch vehicle. Its chemical properties are essentially the same as the original material and both resins met the applicable Military Specification.

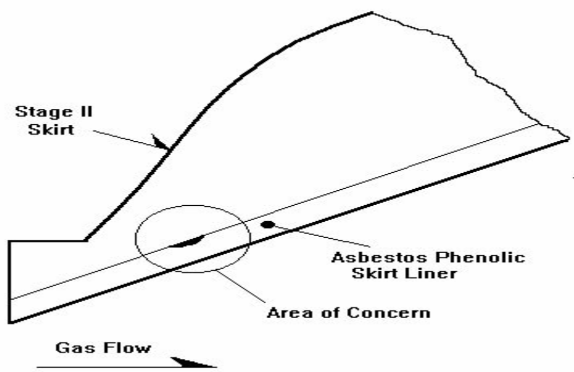
Aerospace Independent Readiness Review

The thermal / structural adequacy of the revised Stage II asbestos phenolic nozzle skirt was assessed by an Aerospace Independent Readiness Review (IRR) team. A team participant, Dr. W. H.

Goodman of the Structural Technology Department, VSD, discovered that the testing performed on the asbestos phenolic with the new resin was not sufficient to establish that the skirt with new resin would perform successfully in the intense thermal environment during the second stage flight operations. In the course of the review, the team discovered that the thermal expansion testing was conducted at a heating rate significantly lower than the flight environment. The low thermal expansion values of both the new and old resin skirts obtained from low heating rate testing had led to an earlier conclusion that the thermostructural integrity of the new skirt was comparable to that of the old skirt. Additional thermal expansion tests at the proper flight environment rate, performed at the IRR's request, revealed that the material with the new resin had distinctly higher thermal expansion than that of the old resin skirt. In lieu of comprehensive material characterization testing and thermostructural analysis, the IRR team requested a hot firing test of the Stage II engine to determine whether the skirt installed in the nozzle of a upcoming Titan flight was flightworthy.
The rationale for this request was based upon knowledge that the original (old asbestos/phenolic material) Titan III skirt was qualified by four successful hot firing tests, while the Titan IV skirt had no hot firing tests. Qualification for the Titan IV skirt with the old resin was achieved by similarity and analysis to the Titan III skirt. This analysis resulted in increasing the liner thickness for the Titan IV skirt by 0.02 inches partly because the Titan IV firing duration was longer than Titan III. When the new resin was introduced, the Titan IV skirt was again qualified by similarity to the skirt made with the old resin. Still, there were no hot firings using the new skirt material. The hot firing test with the new resin skirt requested by the IRR team was approved and ordered by the Air Force. The test was considered an expeditious way of qualifying the new resin used in the complex material system.

Nozzle Static Hot Firing Test

The skirt used in the hot firing test was manufactured, using the new resin material, like the one installed on the upcoming flight except the aft end was truncated to account for the atmospheric pressure effect at the sea level firing conditions. The engine hot firing, planned for 110% of flight duration, was conducted at Aerojet in Sacramento on 28 July 1995. The test appeared to be going well until flames burned through the nozzle and the skirt failed at about 225 seconds into the 253-second firing test, 7 seconds prior to the nominal burn time of 232 seconds. Post-test data review revealed that the temperature at some locations reached 1000 deg F, compared to a predicted level of 850 deg F. The review also indicated that the asbestos phenolic skirt began to experience local debond and delamination as early as 80 to 100 seconds into the firing (see figure.) This phenomenon may explain why the hydraulic actuators on the Stage II engine showed some minor pressure spikes on flight telemetry on some earlier flights of the Titan IV vehicles and also indicate that the skirt made with the original resin may have been just barely acceptable. At the time of the IRR, the two Titan IV boosters being prepared for launch had Stage II nozzle skirts made from the new material. Because of this test failure, a decision was made to destack the vehicles and use some of the seven remaining skirts fabricated from the earlier material.



Lessons Learned

This test firing demonstrated that the risk of a flight failure was very high for skirts made with the new resin. By identifying concerns prior to launch by the IRR team on the qualification status of the new resin used on the Stage II engine nozzle skirt, the technical experts at Aerospace may very well have averted a Stage II skirt failure in flight which could have resulted in inadequate booster performance to make the required mission orbit. Averting a billion dollar launch failure points to the value of the Aerospace/Air Force IRR function.

The IRR experts identified the inadequacy of this composite material change due mainly to Aerospace's role of overseeing all spacecraft and launch programs and applying experiences gained from one program to other programs. In addition, since Aerospace is operating as an FFRDC which was established to meet special long-term research and development needs that cannot be met as effectively by the government or contractor resources, our technical staff members have the advantage of working freely with other government agencies and NASA centers. For example, the Titan IV Stage II skirt test incident demonstrates the value of our participation in NASA's Solid Propulsion Integrity Program (SPIP) which has strengthened our staff's knowledge of phenolic composites and their testing and facilitated the identification of the Titan skirt qualification deficiency.